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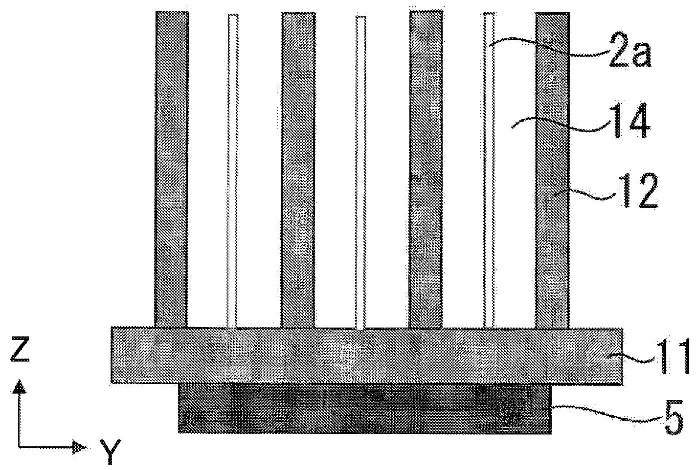
(54) COOLING DEVICE

(57) A cooling device according to the present invention is provided with a heat sink having a plurality of fins, and a plasma actuator is provided in the flow path between the fins.

Since electrodes of the plasma actuators are provided offset in the flow path direction and the induced air flow that is generated is stronger in the central region of the flow path than near the fins, a large amount of air is introduced into the flow path, thereby improving cooling efficiency.

[FIG. 4]



EP 4 481 807 A1

Description

[Technical Field]

[0001] The present invention relates to a cooling device, and more particularly to a heat sink provided with a plasma actuator.

[Background Art]

[0002] Converters and other types of power conversion devices include electronic components which produce heat, such as semiconductors, capacitors, and coils, and heat sinks are attached to these electronic components to cool them.

[0003] In recent years, there has been growing demand for smaller power conversion devices with higher power output; however, if the electronic components of such power conversion devices are arranged more compactly to achieve a smaller device footprint, the density of the heat-generating elements in these devices increases, and due to the higher power output, the amount of heat produced by the heat-generating elements also increases, resulting in the need to improve the performance of heat sinks that cool such heat-generating elements.

[0004] Since, in general, the cooling performance of a heat sink depends on volume (thermal capacity), material (thermal conductivity), and surface area relative to shape (heat transfer area), if the heat sink itself is made larger in order to improve its cooling performance, the overall size of the power conversion device is made larger, thereby increasing the difficulty in downsizing the power conversion device.

[0005] Patent Document 1 discloses using a desired shape for the fins of a heat sink relative to the direction of air flow so as to disrupt the air flow over the entire area from the base to the tip of the fins, thereby preventing the air flow from stagnating and thus improving the heat dissipation performance of the heat sink.

[Prior Art Documents]

[Patent Documents]

[0006] [Patent Document 1] Japanese Laid-Open Patent Application No. 2009-290004

[Summary of the Invention]

[Problem to Be Solved by the Invention]

[0007] However, the heat sink in Patent Document 1 is subject to a significant pressure loss due to the disruption of the air flow by the fins, creating the need to strengthen the air flow in order to fully utilize the cooling performance of the heat sink, in turn necessitating the provision of a large fan, which makes improving the cooling efficiency of the heat sink and downsizing the power conversion device difficult.

[0008] The present invention was devised in light of these issues of the prior art, and has as an object to provide a cooling device with good cooling efficiency and with which a power conversion device or the like can be downsized.

[Means for Solving the Problem]

[0009] As a result of diligent study to realize the above-mentioned object, the inventors arrived at the present invention, having found that by generating an induced air flow in the center of the flow path of the heat sink, which has a flow path formed by a plurality of fins, more air can be introduced into the above-mentioned flow path, thereby achieving the aforementioned purpose.

[0010] Specifically, the cooling device according to the present invention is provided with a heat sink in which a flow path is formed between adjacent fins, and with a plasma actuator. The plasma actuator has electrodes that are arranged offset in the flow path direction, and is configured to generate an induced air flow flowing in the central region between the adjacent fins in the direction of the flow path.

[Effects of the Invention]

[0011] By the present invention, a cooling device can be provided that has good cooling efficiency and allows a power conversion device to be downsized, wherein an induced air flow is generated in the central region of the flow path in the heat sink, making it possible to introduce a large amount of air into the flow path.

[Brief Description of the Drawings]

[0012]

Figure 1 is a perspective view showing an example of a heat sink that can be used in the present invention.

Figure 2 is a cross-sectional view showing an example of a plasma actuator to be provided in the flow path of the heat sink.

Figure 3 is a cross-sectional view showing another example of a plasma actuator to be provided in the flow path of the heat sink.

Figure 4 is a cross-sectional view showing an example of plasma actuators arranged in the flow path of the heat sink.

Figure 5 is a cross-sectional view showing another example of plasma actuators arranged in the flow path of the heat sink.

Figure 6 is a cross-sectional view showing an example of a plasma actuator in which lines of force generated between electrodes are stronger in the central region of the flow path.

Figure 7 is a view showing an example of lines of force generated between the plasma actuator electrodes shown in Figure 6.

Figure 8 illustrates induced air flow when a plurality of plasma actuators are disposed in a flow path.

[Embodiments]

[0013] A cooling device according to the present invention will now be described in detail. The cooling device according to the present invention is provided with a heat sink in which flow paths are formed between adjacent fins, and plasma actuators.

[0014] The heat sink shown in Figure 1 is a heat sink in which a plurality of parallel flat fins are provided upright on a base plate, with a support plate, not shown, provided at the top of the fins to form flow paths for air flows between the fins together with the base plate.

[0015] Since the plasma actuators of the present invention provided in the flow paths are such that a plurality of electrodes are provided offset in the flow path direction, the electric field generated between these electrodes is biased in the flow path direction.

[0016] Therefore, the positive ions or electrons in the low-temperature plasma generated by applying an AC voltage between the electrodes, causing an atmospheric-pressure barrier pressure discharge, are accelerated in one direction by the electric field biased in the flow path direction, and collide with surrounding air molecules, generating an induced air flow in the flow path direction (the x-axis direction in Figure 1).

[0017] In the cooling device of the present invention, the induced air flow generated by the plasma actuators flows more toward the area between adjacent fins rather than near the fins, i.e., toward the central region of the flow path (the center in the y-axis direction in Figure 1), resulting in little friction between the induced air flow and the fins and less of a decrease in flow velocity of the above-mentioned induced air flow, which increases the suction force that draws air outside the flow path into the flow path.

[0018] Specifically, on the downstream side of the plasma actuator, the air in the flow path is pushed out by the induced air flow, and on the upstream side, air is drawn into the flow path, thus increasing the amount of air flowing through the flow paths and improving thermal conductance from the fins to the air, thereby enhancing cooling efficiency. Therefore, the cooling device according to the present invention allows for downsizing power conversion devices, etc., as there is no need for a large fan.

[0019] Note that in the present invention, the "central region of the flow path" is the area away from the fins, and does not mean the center line of the flow path, so that the place where the induced air flow is strongest may be off the central line of the flow path.

[0020] Examples of plasma actuators that produce an induced air flow in the central region between adjacent fins include plasma actuators provided in the central region of the flow path or plasma actuators having electrodes disposed in the fins forming the flow path so as to increase the strength of the lines of force produced between the electrodes in the central region of the flow path.

[0021] First, the plasma actuators provided in the central region of the flow path are described. As shown in Figure 2, for example, the plasma actuator provided in the central region of the flow path has a dielectric layer, an upstream electrode, and a downstream electrode, wherein the upstream electrode is exposed on the surface of the dielectric layer, the downstream electrode is incorporated into the dielectric layer, and the downstream electrode is offset relative to the upstream electrode in the in-plane direction of the dielectric layer.

[0022] Therefore, when an AC current is applied to the plasma actuator, an atmospheric-pressure barrier discharge is generated on the surface where the upstream electrode is exposed, and since the electric field generated between the electrodes that are offset relative to each other is biased in the flow path direction, the electric field causes the positive ions or electrons to accelerate from the upstream electrode to the downstream electrode in the in-plane direction of the dielectric layer, generating an induced air flow in one direction.

[0023] This plasma actuator is provided away from the fins making up the flow path and parallel to the fins so that the induced air flow is in the flow path direction (x-axis direction), thereby making it possible to produce the induced air flow in the central region of the flow path.

[0024] A plasma actuator provided to the central region of the flow path can be used that not only generates an induced air flow on one side as shown in Figure 2, but also generates an induced air flow on both sides.

[0025] For example, as shown in Figure 3, by providing the upstream electrodes exposed from the dielectric layer on both front and rear surfaces of the dielectric layer, and providing the downstream electrode incorporated into the dielectric layer in a position offset relative to the upstream electrodes, an induced air flow is generated on both sides of the plasma actuator, enhancing the suction force drawing air into the flow path.

[0026] The length of the plasma actuator in the flow path direction is preferably shorter than the length of the flow path. A longer plasma actuator will result in friction between the induced air flow which is generated and the surface of the plasma actuator, slowing the speed of the induced air flow as the air flow moves away from the location the air flow was generated, which tends to reduce the suction force drawing air into the flow path.

[0027] The depth of the plasma actuator in the height direction (z-axis direction) of the flow path may be the same as the height of the flow path or shorter than the height of the flow path, but if the depth of the plasma actuator in the height direction of the flow path is the same as the height of the flow path, an induced air flow can be generated along the entire area of the flow path in the height direction, thereby increasing the suction force drawing air into the flow path.

[0028] The thickness of the plasma actuator is preferably 20% or less of the flow path width, i.e., the y-axis direction distance between adjacent fins. By making the thickness of the plasma actuator 20% or less of the flow path width, the plasma actuator is less likely to obstruct the air flow in the flow path, preventing an increase in pressure loss due to the plasma actuator and improving cooling efficiency.

[0029] Further, the distance between the surface of the plasma actuator and the surface of a fin is preferably 10 mm or less. If the distance between the fin and the surface of the plasma actuator generating the induced air flow is too great, the range within which induced air flows are generated becomes smaller relative to the flow path width, which tends to reduce the suction force drawing air into the flow path. Note that "the surface of the plasma actuator" here means the surface where the induced air flows are generated.

[0030] The plasma actuator may be disposed upright on the base plate of the heat sink, as shown in Figure 4, or as shown in Figure 5, the plasma actuator may be provided upright on a support plate separate from the heat sink and then inserted between the fins and arranged in the flow path.

[0031] If the plasma actuator is provided upright on the base plate of the heat sink, the plasma actuator itself can be made to function as part of the heat sink, which enhances cooling efficiency.

[0032] Further, by inserting the plasma actuator provided upright on the support plate into the flow path, the plasma actuators can be provided to a common comb-type heat sink as well, allowing use of commercially available heat sinks, which can reduce cost.

[0033] An example of a plasma actuator with electrodes arranged so that the lines of force are strongest in the central region of the flow path is a plasma actuator in which are formed a first electrode provided on a fin on one side of the flow path, a second electrode provided on the same fin on the same side of the flow path, and a third electrode provided on another fin on the other side of the flow path, where the latter two electrodes are downstream of the first electrode.

[0034] As shown in Figure 6, in this plasma actuator, the first electrode provided on the one fin is exposed on the dielectric layer, whereas the second electrode provided on the same fin as the first electrode and the third electrode provided on the other fin are covered by the dielectric layer.

[0035] Further, the electric potential of the second and third electrodes has an opposite polarity of the first electrode so that a low-temperature plasma is generated when an atmospheric-pressure barrier discharge occurs between the first electrode and the second or third electrode.

[0036] The electric field formed between the electrodes accelerates the low-temperature plasma to generate an induced air flow; thus, by adjusting the positions of the second and third electrodes relative to the first electrode or the electric potentials of the second and third electrodes so that the above-mentioned electric field is oriented toward the central region of the flow path, an induced air flow can be generated in the central region of the flow path, thereby making it possible to reduce pressure loss due to the plasma actuator.

[0037] Figure 7 shows an example of the lines of force formed between the first electrode and the second and third electrodes when the second and third electrodes are at the same electric potential.

[0038] As shown in Figure 7, by providing the third electrode, which is at the same polarity as the second electrode, to a different fin than the fin on which the first and second electrodes are provided, the lines of force are drawn towards the third electrode and are therefore oriented toward the central region of the flow path, thereby generating an induced air flow in the central region of the flow path.

[0039] As shown in Figure 8, in addition to the plasma actuator generating an induced air flow in the central region of the flow path, the cooling device according to the present invention can be provided with a plasma actuator that generates an induced air flow near the fin.

[0040] The induced air flow generated by the above-mentioned plasma actuator not only slows down as the induced air flow moves downstream due to friction with the fin, but also forms a boundary layer with lower flow velocity on the surface of the fin, which reduces the thermal conduction from the fin to the air.

[0041] By providing a plasma actuator that generates an induced air flow near the fin, the induced air flow can be re-accelerated and the generation of a boundary layer can be suppressed, so that a decrease in cooling efficiency due to the boundary layer can be prevented from occurring.

[0042] The configuration of the plasma actuator that generates an induced flow near the fin is the same as the plasma actuator shown in Figure 2, except that the plasma actuator is provided on the fin.

[0043] The plasma actuator that generates an induced air flow near the fin is preferably provided downstream in the direction of the induced air flow from the plasma actuator generating an induced air flow in the central region of the flow path away from the fin.

[0044] The induced air flow generated by the plasma actuator that generates an induced air flow in the central region of the flow path spreads out over the entire flow path from the central region of the flow path and towards the fins, moving downstream due to the difference on velocity between the central region of the flow path and the area near the fins.

[0045] As shown in Figure 8, by providing the plasma actuator that generates an induced air flow near the fin downstream to accelerate the air flow near the fin, air flows throughout the flow path, increasing the cooling efficiency.

[0046] Note that Figure 8 only shows one plasma actuator that generates an induced air flow in the central region of the flow path rather than near the fin and one plasma actuator that generates an induced air flow near the fin, but a plurality of the above-mentioned plasma actuators may be provided depending on the length of the flow path. The locations of the plasma actuators provided in adjacent flow paths separated by fins may be the same or different between adjacent flow paths.

[0047] The cooling device according to the present invention may include a fan which causes a main air flow to flow through the flow path in the same direction as the induced air flow. By directing the main air flow to the heat sink using the fan, the amount of air introduced into the flow paths increases in combination with the plasma actuators, improving cooling efficiency.

[0048] The cooling device according to the present invention has been described using as an example a case in which the fins of the heat sink are flat fins, but as long as the fins form flow paths, the fins are not limited to flat fins, and may be offset fins or pin fins.

[Explanation of the Reference Numerals]

[0049]

1	Heat sink
11	Base plate
12	Fin
13	Supporting plate
14	Flow path
2	Plasma actuator
2a	Plasma actuator that generates an induced air flow in the central region of flow path
2b	Plasma actuator that generates an induced air flow near the fins
21	Upstream electrode
22	Downstream electrode
23	Dielectric layer
24	First electrode
24e	Charge of first electrode
25	Second electrode
25e	Charge of second electrode
26	Third electrode
26e	Charge of third electrode
27	Plasma
28	Induced air flow
3	AC power source
4	Fan
41	Main flow
5	Heat generating body

Claims

1. A cooling device comprising:

a heat sink in which a flow path is formed between adjacent fins; and
a plasma actuator,
the plasma actuator having electrodes arranged offset in a flow path direction, and being configured to generate an induced air flow flowing in a central region between the adjacent fins in the flow path direction.

2. The cooling device according to claim 1, wherein

the plasma actuator that generates an induced air flow in the central region between adjacent fins is provided away from the fins constituting the flow path, and
the length of the plasma actuator in the direction of the flow path is less than the length of the flow path.

3. The cooling device according to claim 2, wherein the plasma actuator has a thickness that is 20% or less of a width between the fins.

4. The cooling device according to claim 2 or 3, wherein a distance between a surface of the plasma actuator and a surface of the fins is 10 mm or less.

5. The cooling device according to any one of claims 2 to 4, wherein
the plasma actuator is provided upright on a base plate of the heat sink.

6. The cooling device according to any one of claims 2 to 5, wherein
the plasma actuator is provided upright on a support member and is inserted between the fins.

7. The cooling device according to claim 1, wherein

the plasma actuator includes a first electrode provided on one of the fins and exposed through a dielectric layer, and a second electrode and a third electrode provided farther downstream in the flow path direction than the first electrode and covered by the dielectric layer,
the second electrode is provided on the same fin as the first electrode,
the third electrode is provided on the other fin, and
an electric potential of the second electrode and the third electrodes has a polarity that is opposite of the first electrode.

8. The cooling device according to claim 7, wherein the second and third electrodes have the same electric potential and are arranged in the same position in the flow path direction.

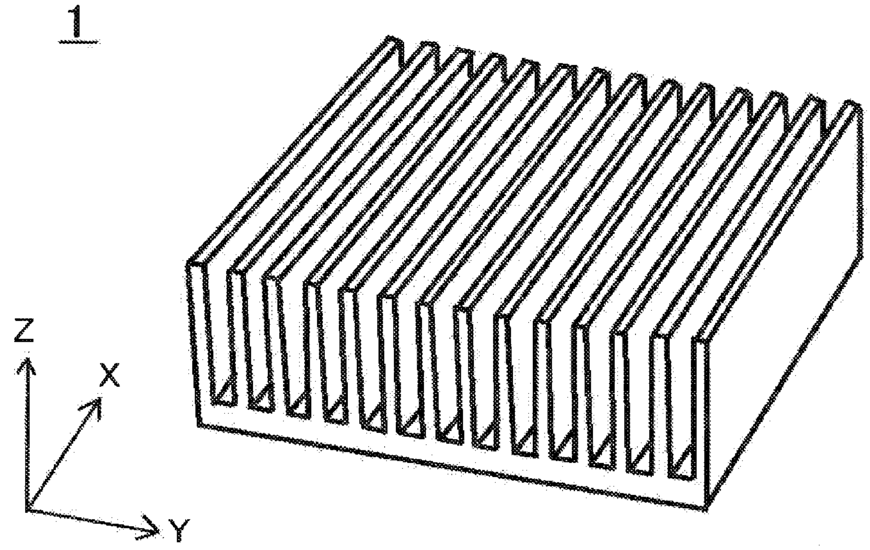
9. The cooling device according to claims 1 to 8, wherein
a plasma actuator provided on one of the fins and

configured to generate an induced air flow near the fin, in addition to the plasma actuator that generates the induced air flow between the adjacent fins.

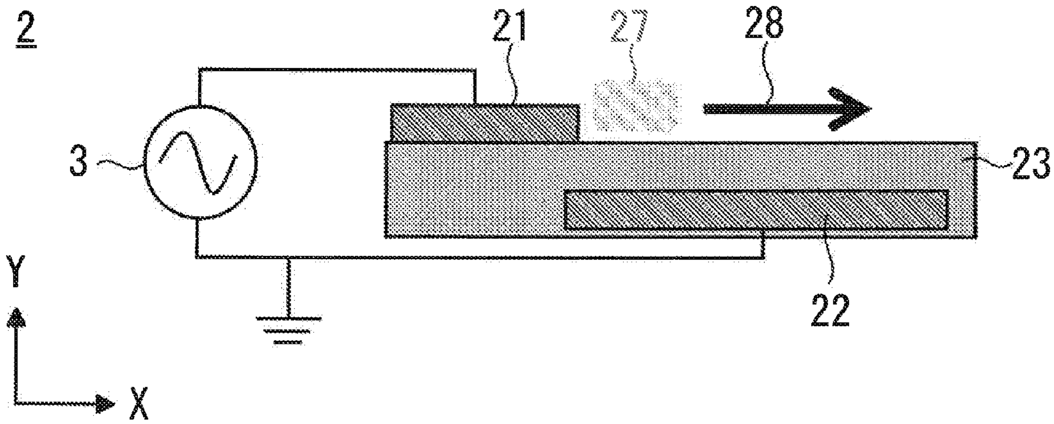
10. The cooling device according to claim 9, further comprising
a plasma actuator provided on the other of the fins to produce an induced air flow near the fins farther downstream in an induced air flow direction than the plasma actuator that produces the induced air flow between the adjacent fins.

11. The cooling device according to any one of claims 1 to 10, further comprising
a fan configured to cause an air flow flowing in a same direction as the induced air flow to flowing through the flow paths.

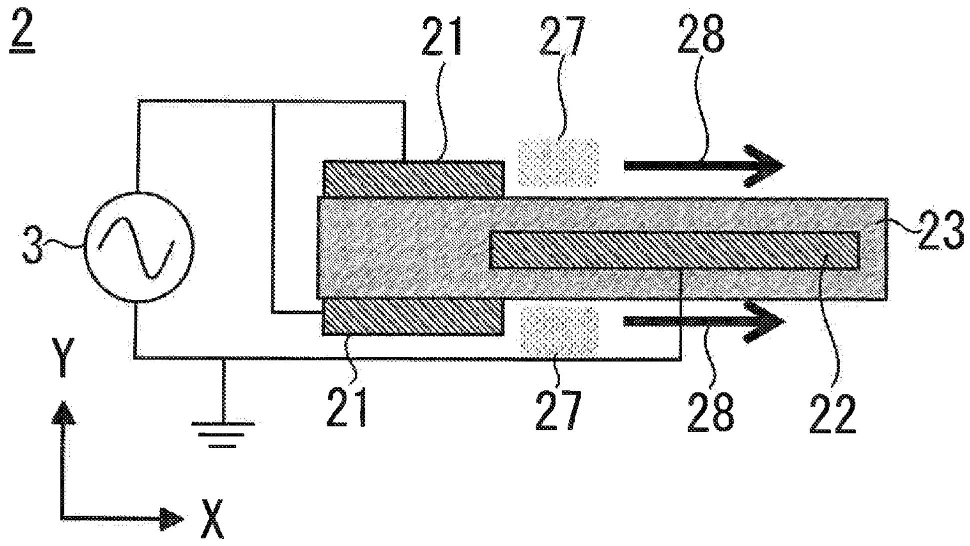
[FIG. 1]



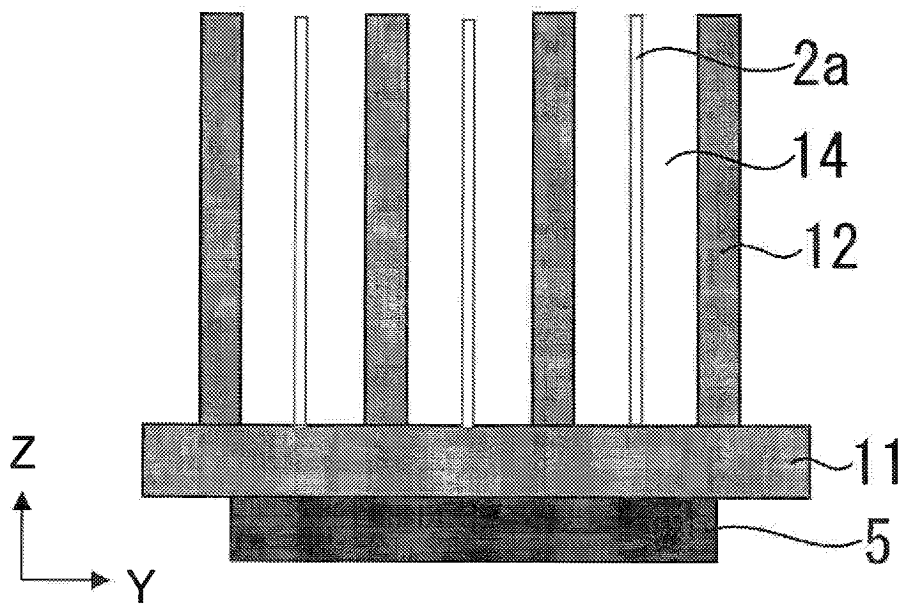
[FIG. 2]



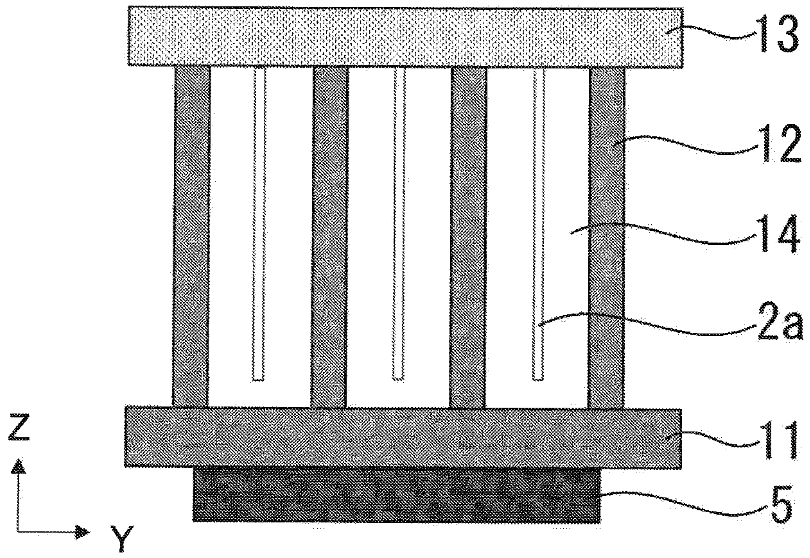
[FIG. 3]



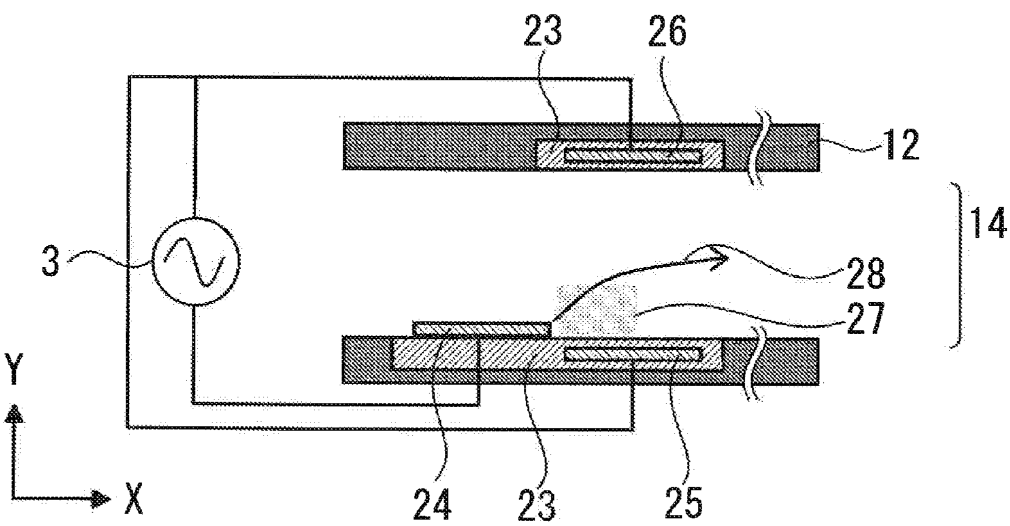
[FIG. 4]



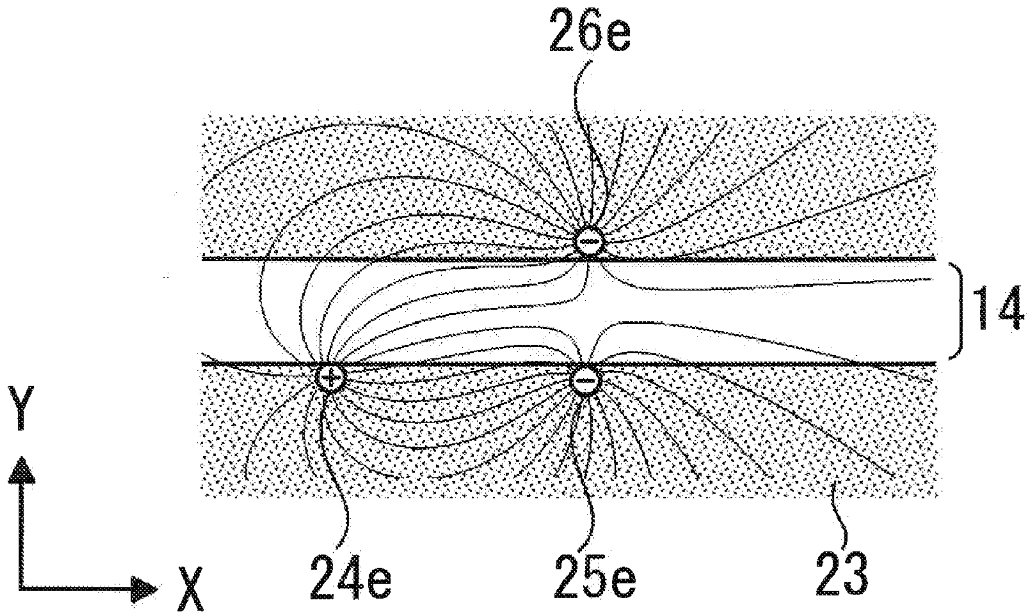
[FIG. 5]



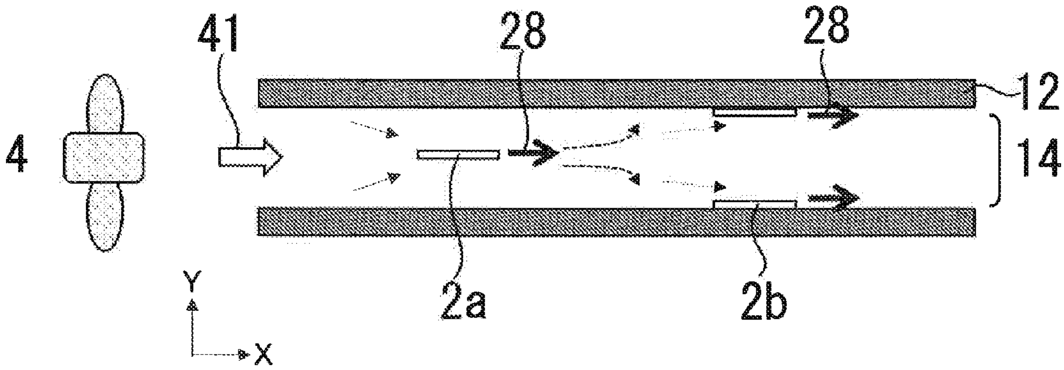
[FIG. 6]



[FIG. 7]



[FIG. 8]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2022/000071

A. CLASSIFICATION OF SUBJECT MATTER

H01L 23/467(2006.01)i
FI: H01L23/46 C

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01L23/467

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2020-57720 A (NISSAN MOTOR CO., LTD.) 09 April 2020 (2020-04-09) paragraphs [0001]-[0161], fig. 7, 8, 18, 23, 25	1, 11
A	entire text, all drawings	2-10
X	JP 2014-183175 A (TOSHIBA CORP.) 29 September 2014 (2014-09-29) paragraphs [0001]-[0028], fig. 10-14	1
A	entire text, all drawings	2-11
A	JP 2016-76350 A (NATIONAL MARITIME RESEARCH INST.) 12 May 2016 (2016-05-12) entire text, all drawings	1-11
A	JP 2011-27365 A (MURATA MANUFACTURING CO., LTD.) 10 February 2011 (2011-02-10) entire text, all drawings	1-11
A	JP 2009-200252 A (SHARP CORP.) 03 September 2009 (2009-09-03) entire text, all drawings	1-11

☐ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

* Special categories of cited documents:
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- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 May 2022	**31 May 2022**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2022/000071

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2020-57720 A	09 April 2020	(Family: none)	
JP 2014-183175 A	29 September 2014	(Family: none)	
JP 2016-76350 A	12 May 2016	(Family: none)	
JP 2011-27365 A	10 February 2011	(Family: none)	
JP 2009-200252 A	03 September 2009	US 2010/0307724 A1 entire text, all drawings	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2009290004 A **[0006]**